Comparative Costs of Iron Pretreatment

A. N. Whiting

A CONSIDERABLE amount of information is now available on the methods of pretreatment of blast furnace iron. This paper does not discuss the detailed operations involved, but attempts to compare the economics of the capital investment and process cost involved.

Pretreatment can be divided into two main types :

Type I Methods which seek to remove a proportion of the silicon.

Type II Methods which seek to remove the silicon and some part of the phosphorus.

As this paper is intended as a basis of discussion on the circumstances which apply in India it deals only with Type I pretreatment.

The phosphorus contents of Indian irons at present used, and the future sources of iron ore are such that it is suggested that phosphorus removal would give no real advantage in subsequent steelmaking operations.

Definition of pretreatment required

In order to assess the cost of Type I pretreatment in each case on a comparative basis it is defined that

(*a*) 10,000 tons of iron from blast furnaces is required to be pretreated per week.

(*b*) Pretreatment is required to reduce the silicon content from 1·0% to 0·3%. It is assumed that the average iron analysis before and after pretreatment in each process will be

	Before pretreatment Wt. %	After pretreatment Wt. %
C ...	3·50	3·20
Si ...	1·00	0·30
S ...	0·05	0·05
Mn ...	1·00	0·35
P ...	0·50	0·50

(*c*) The blast furnace plant delivers iron to the pretreatment station in ladles containing 50 tons metal.

(*d*) The pretreatment plant must deal with 50 tons of metal every 50 minutes.

(*e*) Only such plant which is necessary for the operation of pretreatment is included for comparison. Storage of metal and storage handling which would be required irrespective of pretreatment are not included.

Type I—Methods of pretreatment

The processes which are discussed are :

(1) Active mixer process
(2) Rotary furnace process
(3) Acid duplex process
(4) Tower process.
(5) Blast furnace runner process
(6) Ladle process

Metal storage and transport required irrespective of pretreatment operation

Irrespective of pretreatment practice, in order to transport molten iron from the blast furnaces to the steel plant, and in order to have a reservoir of molten iron available it is necessary to have certain items of plant. These items of plant are listed below and are assumed common to all types of pretreatment process, and fully occupied i.e. it is not assumed that there is spare capacity in any of these plant items which can be utilised for a pretreatment process.

Plant Item	No.	Capacity Unit
Blast furnaces ...	2	750 tons/day
Blast furnace iron runners	2	—
Iron transfer ladles ...	15	50 tons (average lining life 7,500 tons)
Mixer charging crane ...	1	75 tons
Inactive mixers ...	2	1,000 tons
Mixer iron transfer ladles	8	50 tons (average lining life 7,500 tons)
Mixer emptying crane ...	1	75 tons
Buildings, stages, etc. ...	1	Set

It has been assumed in this paper that the capital cost of pretreatment plant for any process is that which is additional to the above plant thus giving as far as possible a true capital cost for the process.

In the same manner, all other costs i.e. fuel, manpower, refractory, etc., given in this paper against a process are those needed in excess of that required by the above plant.

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Active mixer process without oxygen

The use of active mixer furnaces for iron pretreatment has been established for many years and a considerable amount of literature is available. Briefly the modern active mixer is similar in design to a tilting open hearth furnace, is fuel fired at rates similar to an open hearth furnace, can charge iron oxides, lime or limestone and is used to assimilate rough slaggy scrap which is unsuitable for steel furnaces.

Plant required

The plant items required to fulfil the pretreatment operation defined in this paper are:

- 2 active mixer furnaces each of 600 tons nominal capacity
- Charging pans
- 1 charging machine @ 5 tons capacity
- Slag pans and carriages
- 1 stockyard crane @ 20 tons
- Stockyard building, furnace building, stages, etc.

Materials required

Fe balance (per ton of pretreated iron produced)

Charged	lb	Fe lb
Blast furnace iron	2,128	2,001
Steel scrap	107	107
Iron oxides	107	64
		2,172

Produced	lb	Fe lb
Pretreated iron	2,240	2,142
Fe in slag (shot and combined) ...		19
Skulls		11
		2,172

Materials required per ton pretreated iron	lb
Blast furnace iron	2,128
Steel scrap	107
Iron oxides	107
Limestone	110
Dolomite fettling material ...	22

Manpower required

This section also treats this requirement in the same manner as was done with plant. The manpower required for mixer storage capacity has been deducted from that required for pretreatment. It is assumed that four operations are required to fill one job for 168 hours/week.

	per mixer	total
Furnace operators	8	16
Charger drivers	4	4
Raw cold materials assembly	4	8
Maintenance (brickwork, mechanical electrical)	4	8
Labourers		8

N.B.—Furnace repair cost of manpower is included in the refractories materials cost.

Active mixer process with oxygen

Several instances have been reported of the use of oxygen gas for the pretreatment of iron in the active mixer furnace. Briefly the aim of this development is to increase the metallurgical work done in a given mixer furnace either by increasing the throughput and keeping the metalloid removal constant, or by increasing the metalloid removal and keeping the output rate at the same level. In this paper it is estimated that by oxygen use the mixer throughput can be increased by 25%.

So far, desiliconising has taken place in mixer furnaces by means of oxygen lances used through the doors of the furnace, with no redesign of furnace nor adequate oxygen lancing equipment design. Thus results are varied and in some cases this line of development has been stopped, but for completeness this method of pretreatment is included here.

Plant required

The plant required is the same as that listed under active mixer with the addition of oxygen lance equipment and oxygen flow control. Fume Cleaning plant is also included.

Materials required

Fe balance (per ton pretreated iron)

Charged	lb	Fe lb
Blast furnace iron ...	2,075	1,951
Steel scrap	214	214
Iron oxides	30	18
		2,183

Produced	lb	Fe lb
Pretreated iron	2,240	2,142
Fe in slag (shot and combined) ...		30
Skulls		—
Fume		11
		2,183

Materials required (per ton pretreated iron)

	lb
Blast furnace iron	2,075
Steel scrap	214
Iron oxides	30
Limestone	110
Dolomite	40
Steel lance	0·5 ft.

Manpower required

	per mixer	total
Furnace operators ...	6	12
Oxygen operators ...	3	6
Charger drivers ...	3	3
Maintenance labourers ...	3	6
Raw materials assembly ...	3	6

Kaldo furnace process

Two rotor processes have been introduced within recent years, the Oberhausen rotor and the Kaldo rotor process. In the field of iron pretreatment, dealing with iron containing 1·0% silicon, it is envisaged that the Oberhausen rotor furnace would have difficulty in containing the foaming slag which would be produced. The Kaldo furnace can by virtue of being capable of operation at varying angles of tilt, provide sufficient freeboard for this desiliconising operation. Thus the Kaldo furnace is here given consideration.

From the documentation available on Kaldo furnace operation the following sections have been calculated.

Plant required

2 @ 30-ton Kaldo furnaces.
Fume hood and ducting, oxygen lances. Fume cleaning plant.
1 @ 50 ton crane.
Kaldo metal transfer ladles.
Slag pans and carriages for desiliconising slag.
Iron ore, lime supply and hoppers.
Buildings, foundations, slag and iron railroad.

Materials required

Fe balance (per ton pretreated iron produced)

Charged	lb	Fe lb
Blast furnace iron	2,251	2,113·0
Iron ore ...	119	71·5
		2,184·5
Produced	**lb**	**Fe lb**
Pretreated iron	2,240·0	2,142·0
Fe in slag (shot and combined)	...	36·5
Fe in fumes	...	6·0
Total		2,184·5

Materials required (per ton pretreated iron produced)

Blast furnace iron ...	2,251 lb
Iron ore ...	119 lb
Lime ...	59 lb

Manpower required

Furnace operators ...	8
Crane drivers ...	4
Raw materials supply ...	8
Maintenance (mechanical & electrical)	8
Labourers ...	8

Acid Bessemer

The acid Bessemer furnace process is established as a method of silicon removal prior to charging in the steel furnace. The method of operation is well known and the following details have been calculated from accumulated published data :

Plant required

3 @ 30-ton acid convertors
1 @ 50-ton crane
Convertor metal transfer ladles
Slag pans and carriages for desiliconising slag
Steel scrap supply
Charging boxes
Charging machine
Buildings, foundations, slag and iron railroads.

Materials required

Fe balance (per ton pretreated iron produced)

Charged	lb	Fe lb
Blast furnace iron	2,217	2,084
Scrap	110	110
		2,194
Produced		
Pretreated iron	2,240	2,142
Fe in slag (shot and combined)		32
Fe in fumes and slop	...	20
		2,194

Materials required (per ton pretreated iron produced)

Blast furnace iron	2,217 lb
Steel scrap	110 lb

Manpower required

Furnace operators ...	8
Crane drivers ...	4
Raw materials supply ...	8
Maintenance ...	8
Labourers ...	8

Tower process

A completely new approach to iron pretreatment has been described in the paper by Mr. J. A. Charles in some detail. The principle of the process is to pass iron in thin streams through a refractory lined tower into which oxygen gas is blown.

The pretreated iron and accompanying slag is collected in a transfer ladle at the bottom of the tower. Although not yet fully proved on the scale indicated for comparative purposes in this paper, there is little doubt of the commercial possibilities of this process.

Plant required

3 towers complete with oxygen supply, fuel supply and fume ducting.
Fume cleaning plant.
Transfer ladles—pretreated iron to steel furnaces.
Slag pans and carriages for desiliconising slag.
Buildings, foundations, slag and metal railroads.

Materials required

Fe balance (per ton pretreated iron)

Charged	lb	Fe lb
Blast furnace iron ...	2,206	2,073
Steel scrap (5% of iron charged) ..	110	110
		2,183
Produced	**lb**	**Fe lb**
Pretreated iron ...	2,240	2,142
Fe in slag (shot and combined) ...		32
Fume ...		9
		2,183

Materials required (per ton pretreated iron)

Blast furnace iron	2,206 lb
Steel scrap	110 lb

Manpower required

Tower operators	8
Oxygen operators	4
Crane drivers	4
Maintenance (mechanical and electrical)	2
Labourers	2

Blast furnace runner process

The problem of pretreatment of iron prior to being used in the Thomas converter has occupied the Continental steel industry for some years, and as the Minette iron ores are gradually increasing in SiO_2 content it will become an important problem in the future.

The French steel industry has tackled the problems in two ways. By modifying the Thomas process they can accommodate a slightly higher silicon content than is normally so, and by desiliconising in the blast furnace runner they can reduce the silicon content to that accepted by this modified converter process.

It is important, therefore, in comparing installation and operation costs to bear in mind the development and although we are including this method here, it is not yet a proven process on a commercial scale for silicon removal from 1·0% to as low as 0·3%. There is, however, a considerable amount of development work being undertaken on this process and we have little doubt that it will achieve this end.

Runner desiliconising takes place as the blast furnace iron flows from the blast furnace to the iron transfer ladle. Oxygen is blown through porous refractory blocks which form the bottom of the runner.

Plant required

Blast furnace runner casing and oxygen supply for each of two blast furnaces rated at 750 tons/day.
Porous blocks.
Oxygen pipework and controls.
Slag pans, slag pan carriages and railroads.
Deslagging platform, buildings and foundations.

Materials required

Fe balance (per ton pretreated iron)

Charge	lb	Fe lb
Blast furnace iron ...	2,215	2,082
Iron oxide ...	150	90
		2,172
Produced	**lb**	**Fe lb**
Pretreated iron	2,240	2,142
Skulls (0·5% of iron) ..		10
Fe in slag (shot and combine)		20
		2,172

Materials required (per ton pretreated iron)

Blast furnace iron	2,215 lb
Iron oxide	150 lb
Lime	50 lb

Manpower required

Process operators	8
Crane drivers	4
Raw material supply	8
Maintenance	2
Labourers	2

Ladle process

The most common method of pretreatment at present in operation is that of oxygen injection into blast furnace iron contained in transfer or special ladles.

Several variations of equipment are used i.e. oxygen lances consisting of bare steel pipe, refractory coated or water cooled pipe, oxygen lancing (i.e. injecting the oxygen below the metal surface) or jetting (blowing the oxygen on to the metal surface), and the variation introduced by the Maximillianhutte method.

In some cases cold steel or iron scrap is added to the ladle to protect the ladle lining life and relieve the steel furnace charging equipment of this quantity, in other cases advantage is taken of charging the preheated iron at a higher temperature.

In some cases the possibility of vanadium recovery precludes the addition of lime or limestone, in others these additions are made to give a lower Fe content of the slag although calculations show that little advantage is gained in total Fe loss by doing this.

On the evidence available at the present time, several conditions can be postulated and this paper uses these as the basis of comparison for ladle pretreatment.

(*i*) If pretreatment follows storage, then the fullest advantage can be taken of the heat increment caused by pretreatment. If pretreatment precedes storage then greater flexibility of supply to the steel furnaces is available.

(*ii*) Satisfactory water cooled lance design to give deep lance penetration into the metal is not available, although such lance design for shallow penetration is available.

(*iii*) Bare pipe or refractory coated lances plunged deeply into the metal and kept at that position by feeding in as they burn away gives minimum statification of pretreated iron analysis.

Plant required

Ladles @ 75 tons capacity.
Fume hoods and oxygen lance equipment.
Fume cleaning plant.
Slagging stands.
Slag pans and carriages.
1 crane at 85 tons capacity.
Buildings, foundations, stages, etc.

Materials required

Fe balance (per ton pretreated iron)

Charged	lb	Fe lb
Blast furnace iron ...	2,206	2,073
Steel scrap ...	110	110
		2,183
Produced		
Pretreated iron ...	2,240	2,142
Fe in slag (shot and combined)		32
Fe in fume		9
		2,183

TABLE I

Comparative costs of pretreatment processes in shillings per ton pretreated iron

	Active mixer	Active mixer with oxygen	Kaldo	Acid Bessemer	Tower	Blast furnace runner	Ladle
Materials cost							
Blast furnace iron	284·9	278·0	301·5	297·0	295·4	296·7	295·4
Steel scrap	12·2	24·4	—	12·5	12·5	—	12·5
Iron oxides	6·7	1·9	7·4	—	—	9·9	—
Limestone	1·5	1·5	—	—	—	—	—
Lime	—	—	6·2	—	—	2·2	—
Dolomite	1·2	2·3	—	—	—	—	—
Steel lance	—	0·5	—	—	—	—	0·5
Total materials cost	306·5	308·6	315·1	309·5	307·9	308·8	308·4
Manpower cost	1·3	1·1	1·0	1·0	0·6	0·7	0·5
Refractories (furnaces and ladles) ...	4·5	4·5	3·6	2·0	1·5	3·2	1·3
Fuel (including ladle heating-up) ...	7·5	5·6	1·0	1·0	0·5	0·1	0·3
Power and water	0·9	0·8	0·7	1·9	0·2	—	0·2
Oxygen	—	2·0	1·3	—	2·0	1·0	2·0
Maintenance	2·0	1·6	1·6	1·6	0·3	0·1	0·2
Total manufacturing cost	322·7	324·2	324·3	317·0	313·0	313·9	312·9
Depreciation (at 10%)	3·8	2·9	2·6	2·1	0·5	0·2	0·5
Total pretreatment cost	326·5	327·1	326·9	319·6	313·5	314·1	313·4

Materials required (per ton pretreated iron)

Blast furnace iron	2,206 lb
Steel scrap	110 lb
Steel lance	0·5 ft

Manpower required

Oxygen operators and slaggers ...	8
Crane drivers	4
Maintenance	2
Labourers	2

Comparison of pretreatment costs and discussions

The information already given along with calculated service, supply, maintenance, and refractory costs is summarised in Table I which compares the total pretreatment cost for each of the processes. The cost prices used are given in Table II.

TABLE II

Cost prices used as a basis of process comparison

Molten blast furnace iron ...	£ 15·0 per ton
Steel scrap	£ 12·75 ,, ,,
Iron oxides	£ 7·0 ,, ,,
Limestone	£ 1·5 ,, ,,
Lime	£ 5·0 ,, ,,
Dolomite	£ 6·0 ,, ,,
Oxygen	5/- per 1,000 cft.
Ladle refractories ...	£ 10·0 per ton
Power	1·0 pence per unit
Average gross wage/operative (including allowance for welfare etc.)	£ 750 per year

There are several interesting points arising from this comparison :

(1) There appears to be little doubt that the Tower, Blast furnace runner and Ladle processes are considerably more economic than Mixer or Kaldo processes, with the acid converter lying midway between.

(2) The difference lies in

(*a*) Greater capital depreciation cost for Mixers and Kaldos.

(*b*) Considerably greater fuel costs for the Mixer processes.

(*c*) Greater maintenance costs for the Mixer and and Kaldo processes.

(3) Of the three more economic processes there appears to be little difference. The choice of installation would then lie with technical advantages of one process against the other two. There is little doubt that provided the full scale operation at present being undertaken is successful in achieving its objectives, the British Oxygen Tower process could show definite advantages technically. These advantages have been outlined in my colleague's paper.

Conclusion

This paper has attempted to compare existing methods of iron pretreatment for a given set of conditions. It has shown advantages offered by the newer type pretreatment processes compared with the long established active mixer, the latter used both with and without oxygen addition.

Of the newer processes i.e. British Oxygen Tower process, blast furnace runner process and ladle process there is little to choose under the conditions set, but alteration of pretreatment requirements could modify this result. Further operating experience in the case of the Tower and the Runner process will be available in the next few months and a more definite conclusion can then be sought.

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DISCUSSIONS

Papers on IRON PRETREATMENT RESEARCH by J. A. Charles, and COMPARATIVE COSTS OF IRON PRETREATMENT by A. N. Whiting

Mr. P. K. Paul, Durgapur Steel Project: The papers are indeed a valuable contribution to the subject of desiliconising in blown metal. May I request the authors to enlighten me on the following points?

(*a*) In Durgapur we are having 200-ton open hearth furnaces and shall be using 70 : 30 ratio of hot metal to scrap, with probably about 70 tons of metal in a single ladle.

I would like to know what maximum weight of metal can be used for desiliconising in a single ladle.

(*b*) It has been said that the silicon content initially at 1%, dropped to 0·3% after treatment. Will the operations in a desiliconising plant be economical when silicon level is of the order of 1·8 to 2·2 in the B.F. iron?

(c) What would be the consumption of O_2 per point drop of Si per ton of hot metal and the time required for such a drop of Si?

Mr. A. N. Whiting, (Author): The maximum size of ladle which has practised desiliconising pretreatment of this order, is of 60 tons capacity.

Regarding your second question, I would say that the economics of desiliconising will depend on the costs involved as compared with the advantages obtained in the later steel making processes.

Mr. J. A. Charles, (Author): The theoretical oxygen requirement for silicon removal is 3·1 cft. per point of silicon (0·01%) removed per ton of metal. The practical efficiency achieved will, of course, depend on several factors such as the initial silicon content, (because at high silicon levels there is a higher removal efficiency), the method of oxygen introduction, as referred to in my paper, and it can also depend to some extent on the nature of the vessel used for the operation. In general, using British irons on a 20-ton scale, ladle desiliconisation gives 70 to 80% efficiency of oxygen usage. The time taken is controlled primarily by the blowing rate and the range of silicon content involved. A typical figure is 20 minutes for about 70 points removed in 20 tons, blowing at 250 cft./min.

Dr. G. P. Chatterjee, Durgapur Steel Project: Considering the raw materials available in India and the pig irons we can produce from them, it will obviously be difficult for us to start desiliconising at a high silicon level. We may have about 1·4 to 1·6% Si level initially.

Now it is a well known physicochemical process, from the kinetic point of view, that the rate of elimination of Si decreases with the rise of temperature. For example, we are well aware that if we operate in an acid converter, starting with high Si content, decarbonisation starts and Si reaction rate is retarted. Now supposing we start with 1·6% Si and blow O_2, the Si will initially decrease fairly rapidly but it is very likely that the rate of removal of silicon will appreciably decrease unless one takes care to bring down the temperature either by the addition of scrap or ore, or by some other heat absorbing reactions.

I would request Mr. Charles to tell us if he has made any particular study of this point, because I feel that desiliconisation will become progressively difficult as we go higher up from 1·6% Si onwards. How far can we go down, keeping in view the efficiency of desiliconisation within a given period of time and with regard to the scrap charge in the ladle?

Mr. J. A. Charles (Author): All our initial desiliconisation work was carried out with 1 cwt. batches of a hematite iron containing 2·5% Si. After the initial period of desiliconisation by oxygen lancing, when the silicon had been removed from 2·5% Si down to about 1·5% Si, the metal temperature had risen to about 1,350°C with an oxygen flow rate of 10 cft./min., or to 1,500°C with a flow rate of 30 cft./min. for a period of blowing of one-third the duration. In spite of the wide difference in metal temperature achieved with the different blowing rates, the amount of silicon removed for a given amount of oxygen injected was the same. This effect is described in the paper. In other words, under our conditions metal temperatures in the range 1,350-1,500°C did not effect the efficiency of silicon removal in high silicon iron.

Mr. A. N. Whiting (Author): We would be much interested to know if Dr. Chatterjee has ever found in the course of his investigation that desiliconisation of very high Si iron is affected by the level of silicon at start of the operations.

Dr. G. P. Chatterjee, Durgapur Steel Project: When pig iron containing high Si is blown in an acid converter, decarbonisation starts and as I have already indicated the rate of removal of Si is progressively retarted. It is also known that the higher the temperature the lower will be the rate of silicon removal. Silicon oxidation being exothermic and carbon oxidation in steel being endothermic—the latter reaction is favoured at a higher temperature and in my opinion, if we start with a high Si level and keep up the same rate of O_2 blowing, the rate of rise of the metal temperature will also correspondingly increase; now with a given rate of rise of temperature, when we have dropped down say from 1·6 to 1% Si, the temperature may be sufficiently high for any further appreciable rate of desiliconisation unless one can keep the temperature under control either by decreasing the rate of oxygen blow or by adding iron ore or cold scrap.

Mr. J. A. Charles (Author): I would like to point out that carbon oxidation in molten iron using oxygen is exothermic, not endothermic as it is in conventional steelmaking practice using cold ore additions.

Dr. T. P. Colclough, British Iron & Steel Research Association, U.K.: Dr. Chatterjee is absolutely correct. It is a matter of long experience that if you have a high Si iron and you blow that in an acid lined vessel, you do have the point at which the Si is not removed and it would therefore have an effect on desiliconisation. This is from theory but in practice, if you are operating with a high silicon you do not permit the temperature of the metal to rise to that danger point because you regulate the amount of scrap which you already have in the ladle in the metal and thereby you get an additional advantage; if the Si is high, of the order of 2% or more, you will then of course increase the amount of scrap in the ladle in order to prevent this condition very rightly mentioned by Dr. Chatterjee.

Mr. S. Sharma, Mysore Iron & Steel Works: Mr. Whiting has compared the costs of the existing methods of iron pretreatment, in a very attractive way. May I request him to enlighten me on the depreciation figure given as 10%. It was stated that this figure is 3·8 for the active mixer and gradually came down to 0·5 for the ladle and 0·2 for the blast furnace runner. Does it mean that the Tower, the blast furnace the ladle, the mixers are not necessary ? Should not the depreciation of the mixer be added to this figure ?

Mr. A. N. Whiting, Davy British Oxygen Ltd., U.K. : We assumed that in the transfer of iron from the blast furnace to the steel plant you need, in any case, some equipment. Whether you desiliconise or not, you will need blast furnace runners, transfer ladles, inactive mixer capacity, cranes and ladles and we thought it unfair to the practice of desiliconisation to add that cost to it. The figures I have given in my paper do not include costs of such transport equipment, as otherwise, it is not the cost of desiliconising that would be arrived at, but the cost of transport as well.